Postprint: Sheltering Effect of Tamarisk Shrub-land Sand Dunes on Beetles at the Northern Margin of the Taklamakan Desert

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Abstract

Taking Tamarix shrub sand dunes-Tamarix cones in a typical desert area on the northern margin of the Taklamakan Desert as the research object, we investigated ground-dwelling beetle diversity on the Tamarix cones and adjacent bare desert land during 2005-2006. The results showed that in both 2005 and 2006, the individual abundance and species number of ground-dwelling beetles on the Tamarix cones were higher than those in the bare desert land. The number of ground-dwelling beetle species on the Tamarix cones was 21 and 16, respectively, while in the bare desert land it was 10 and 12, respectively, indicating that species richness on the Tamarix cones was significantly higher than that in the bare desert land. The dominant species, Penthicicus koltzei Reitter, was selected for estimation of relative population density. This species was distributed in greater numbers on the Tamarix cones, with densities reaching more than 13 individuals per square meter, whereas the bare desert land had only about 6 individuals. Tamarix cones serve as an obvious refuge for beetle diversity, which is beneficial for maintaining beetle species diversity. The abundance of ground-dwelling beetles showed significant seasonal variation under the two different habitat conditions, with peaks occurring in June 2005 and July 2006, which may be related to food abundance resulting from seasonal environmental extremes (such as temperature peaks and flood timing).

Full Text

The Shelter Belt Effect: Beetles in the Litter Layer of Tamarix Nebkha on the Northern Edge of the Taklamakan Desert

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Abstract

Tamarix nebkhas have been widely planted to stabilize sand movement and develop soils along desert margins, yet the influence of this man-made localized landscape on insect diversity remains poorly understood. Certain beetle groups are well adapted to the arid and thermally stressful environments characteristic of desert regions. During 2005 and 2006, we investigated the species diversity and abundance of litter-layer beetles in planted nebkha areas and adjacent bare patches on the northern edge of the Taklamakan Desert, China' s largest sand dune area and the second largest globally in terms of dune movement. Six nebkha areas and contiguous bare patches were monitored from June to August in both years using pitfall traps. Beetles from each trap were collected at half-month intervals and preserved in alcohol for later identification. A mark-recapture method was employed to estimate beetle density and the probability of movement between nebkhas.

The litter-layer beetle community in nebkhas was higher and more stable than in bare patches. In 2005 and 2006, the total number of beetles collected in nebkhas was 360 and 209 individuals respectively, greater than the 209 and 158 individuals collected in bare patches. Twenty-one litter-layer beetle species were observed in nebkhas versus ten species in bare patches in 2005, with 16 and 12 species trapped in each patch type in 2006. Species richness, Shannon-Weiner index, and evenness index were higher at nebkhas than in bare patches, while Simpson Index was greatest in bare patches in 2005. Based on mark-recapture data, the density of *Penthicicus koltzei* Reitter was higher in nebkha areas (13 individuals/m^2) compared to bare patches (6 individuals/m^2). Nebkhas act as a refuge for conserving beetles and other insects in desert areas. Beetle movement was highly localized; only one beetle was recorded moving from one nebkha to another, a distance of 30 m, implying that beetle populations in nebkhas might be independent and that refuges are highly localized.

High seasonal variability occurred in litter-layer beetle species abundance and biodiversity between the two patch types: beetle density in both areas peaked in June 2005 and July 2007. This may be attributed to food abundance for beetles in different seasons and microhabitat effects, particularly moisture effects in harsh desert areas. Nebkhas alongside deserts offer a refuge, sustaining beetle diversity. Expanding the creation of this distinctive landscape composed of nebkhas and its biodiversity provides a buffer between desert and agricultural reclamation and should be a priority.

Keywords: litter-layer beetles; *Tamarix nebkha*; shelter effect

Introduction

Plant community composition and distribution characteristics, particularly species number and height, are closely related to insect community structure and species diversity, profoundly influencing insect community stability. In deserts or arid regions, the relationship between plants and insects is even more intimate due to resource scarcity and environmental stress. In the Sonoran Desert, plant communities provide substantial resources for insects, contributing to increased insect diversity, where leaf biomass above a certain level can explain variation in species number and population abundance, and biomass above certain thresholds explains variation in insect species composition. Insect diversity also correlates with water content in host plants, with positive relationships documented in some plant groups. Wenniger et al.' s work similarly supports that insect diversity is positively correlated with plant diversity and irrigation. Insect community structure and species diversity in the same habitat are influenced not only by plant communities but also by environmental factors such as soil hardness and water content, and show obvious changes with seasonal progression, causing distinct seasonal fluctuations in different insect populations.

Plant community distribution in desert regions is affected by multiple factors including soil biological crusts, soil environment, and geographic location, which may indirectly influence insect diversity. Harsh environments result in impoverished insect species numbers in these areas. Nebkhas are a typical aeolian biogeomorphic type in arid regions. The Tarim Basin, located in southern Xinjiang, is an extremely arid area with harsh natural conditions and a fragile ecosystem where populations are extremely limited. Shrub nebkhas can improve local microenvironments through litter enrichment and stemflow collection, thereby attracting herbivorous insects and carnivorous animals to inhabit them, providing shelter for biodiversity conservation in extremely arid regions. Tamarix nebkhas are one type of shrub nebkha, mainly distributed in piedmont alluvial fans, low river terraces, and areas between oases and moving dunes. While the "fertile island" and "salt island" effects of Tamarix have been reported, few studies have addressed their function in arid ecosystems, such as maintenance and conservation of insect community diversity.

This study compares differences in species composition, individual abundance, and diversity of ground-dwelling beetles between Tamarix nebkhas and bare desert areas in typical desert regions, analyzing seasonal dynamics to investigate the mechanisms by which Tamarix nebkhas maintain and conserve ground beetle community diversity in extremely arid areas, and to further understand the complex ecological relationships between animals and plants in desert regions, thereby providing theoretical support for biodiversity conservation and management in fragile ecosystems.

1 Study Area Overview

The study area is located in Kalakule Town (40°22 N, 80°03 E) on the northern edge of the Taklamakan Desert along the upper reaches of the Tarim River, at the confluence of the Hotan and Yarkant Rivers, 130 km from oasis shelterbelts. The region experiences a typical warm temperate extreme continental arid desert climate, with rapid spring warming that is unstable, rapid autumn cooling, large diurnal temperature variations, and a multi-year average temperature of 11°C. Extreme minimum temperature is -27.1°C, extreme maximum temperature is 43.9°C, average annual precipitation is 62.7 mm, and average annual evaporation is 2337.5 mm. The elevation is 1050 m.

The area is dominated by rolling sand dunes with low habitat heterogeneity, scattered with few Tamarix nebkhas, sparse plant species, and minimal human disturbance, making it an ideal site for studying ground beetle community structure and dominant species density in natural habitats.

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2 Survey Methods and Data Processing

2.1 Beetle Community Diversity Survey

Ground beetle community diversity was surveyed using pitfall traps. Traps consisted of plastic cups measuring 7 cm in diameter and 12.5 cm in depth, with cup rims level with the ground surface. Due to high evaporation in the study area, no attractants were used. Along the perimeter of each nebkha, traps were placed uniformly at intervals, with six nebkhas serving as experimental sample sites. Each bare desert sample area had traps spaced at intervals. The sampling interval was half a month from June to August in both 2005 and 2006. Beetle specimens were preserved in 70% alcohol solution. Identification was primarily completed with the assistance of experts specializing in various taxonomic groups; groups not examined by experts were identified to family level through literature review.

Basic characteristics of the six Tamarix nebkhas

2.2 Dominant Species Density Survey

The dominant species density survey was conducted from July 16-26, 2006. Six nebkhas with pairwise distances of no less than 30 m were selected. At the base of each nebkha, traps were placed uniformly at intervals. A mark-recapture method was used to estimate the population size of the dominant beetle species on each nebkha. Captured beetles were marked on one elytron with paint, with the same color used for specimens captured on the same nebkha and different colors for different nebkhas. Specimens were checked daily for marked and unmarked individuals.

The Schumacher-Eschmeyer formula was used to estimate the population size of dominant beetles on each nebkha:

Population size estimate (N) and its variance were calculated as:

$$\hat{N} = \frac{\sum(M_i^2/n_i)}{\sum(M_i m_i/n_i)}$$

where: - m_i = total number of marked beetles captured in the ith sample - n_i = total number of beetles captured in the ith sample - M_i = total number of marked beetles in the population at the ith sampling occasion

The 95% confidence interval for $\hat{N}$ was derived from the variance estimate.

2.3 Diversity Indices

Species richness (S) refers to the number of species in a community. Community diversity was calculated using the Shannon-Wiener index (1963):

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i)$$

where p_i is the proportion of individuals of species i relative to the total number of individuals in the community, N_i is the number of individuals of species i, N is the total number of individuals, and S is the number of species.

Evenness index was calculated as:

$$E = \frac{H'}{H'_{\max}}$$

where $H'_{\max}$ is the maximum theoretical value of H' (when all species are equally abundant).

Simpson' s dominance concentration index was also calculated, where n_i is the importance value of the ith dominant species and N is the total importance value of the community.

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3 Results

3.1 Ground Beetle Community Structure and Abundance in Nebkhas and Bare Desert

During the 2005 and 2006 surveys, both individual abundance and species numbers of ground beetles were higher on nebkhas than in bare desert areas. In 2005, a total of 360 ground beetles were captured on nebkhas and 209 in bare

desert patches. In 2006, 209 beetles were captured on nebkhas and 158 in bare desert. With equal numbers of traps, the abundance on nebkhas was 1.7 times that of bare desert in 2005 and 1.3 times in 2006.

Twenty-one litter-layer beetle species were observed on nebkhas versus ten species in bare desert patches in 2005, with 16 and 12 species trapped in each patch type in 2006 respectively. Species richness, Shannon-Weiner index, and evenness index were higher on nebkhas, while Simpson' s index was greater in bare desert patches in 2005. These results indicate that the stability of ground beetle communities on nebkhas is higher than in bare desert areas.

Characteristics of litter-layer beetle communities between Tamarix nebkhas and bare desert

3.2 Seasonal Dynamics of Ground Beetles in Nebkhas and Bare Desert

Data were standardized by the number of beetles per trap. In 2005, beetle abundance in both nebkhas and bare desert decreased sequentially from June through August. In 2006, beetle numbers on nebkhas increased from June, peaking in July, then decreased in August and September. Seasonal dynamics in bare desert generally followed the same pattern as on nebkhas, though the timing of peaks differed between years, likely related to interannual variation in the timing of maximum temperatures. The 2005 peak occurred in June, while in 2006 it shifted to July.

The shading effect of Tamarix and relatively abundant food resources can attract more ground beetles to nebkhas. The microenvironmental effects of nebkhas become more pronounced under extreme conditions, as high surface temperatures in July may amplify the difference between nebkhas and bare desert. The seasonal dynamics of the dominant species *Penthicicus koltzei* were similar to overall ground beetle patterns, suggesting that desert ground beetles share similar trends in adapting to extreme environments.

[Figure 1: see original paper] Seasonal dynamics of litter-layer beetles between Tamarix nebkhas and bare desert
[Figure 2: see original paper] Seasonal dynamics of the dominant species (*Penthicicus koltzei*) between Tamarix nebkhas and bare desert

3.3 Density Estimation of Dominant Beetle Species on Nebkhas

The mark-recapture process and density of *Penthicicus koltzei* on nebkhas are shown in Table 3. The 2006 survey revealed that the dominant beetle species *Penthicicus koltzei* occurred in relatively large numbers on nebkhas, with densities reaching 13 individuals/m^2. Nebkhas 2, 4, and 5 had relatively high densities, corresponding to their characteristics of thicker litter layers and greater accumulation of plant organic matter, which benefit beetle survival and food acquisition. Nebkhas 1, 3, and 6 had thinner litter layers and fewer beetles.

During the survey, one specimen marked with green paint on nebkha No. 2 was captured on nebkha No. 5, a distance of 30 m, indicating some migration between similar habitats. However, beetle movement was highly localized overall.

Mark-recapture investigation of *Penthicicus koltzei* on nebkhas
Abundance of *Penthicicus koltzei* on the six nebkhas

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4 Discussion and Conclusion

4.1 Nebkhas Function as Shelters Conserving Ground Beetle Diversity in Arid Ecosystems

This study demonstrates that both species diversity and dominant species population abundance of ground beetle communities on nebkhas are significantly higher than in bare desert, indicating that nebkhas serve as shelters for ground beetles in arid ecosystems. This shelter function arises because shrub nebkha formation reduces wind speed while improving sandy soil properties and increasing soil nutrient content. The accumulation of ground litter provides abundant resources for herbivorous and detritivorous insects. Excellent water retention conditions provide safe oviposition sites for ground beetles, thereby improving local microenvironments. Compared to the exposed high-temperature conditions of bare desert, nebkha habitats have relatively lower temperatures, often referred to as the "fertile island" and "insect island" effects of shrubs. Additionally, nebkha habitats have better ground cover, providing suitable sites and conditions for beetle habitation and predator avoidance. This study confirms that ground beetles preferentially select nebkha environments with higher ground cover accumulation during habitat selection.

Herbivorous insects were observed feeding on Tamarix plants and their litter during the day. Darkling beetles were observed foraging on plant leaves and flowers, and besides feeding, were seen chasing each other on nebkhas to complete mating. While this study did not systematically monitor other insect groups, large numbers of pollinating insects were observed visiting nebkhas during Tamarix flowering periods. Lizard abundance was also noticeably higher on nebkhas, indicating that nebkhas positively impact not only insect diversity conservation but also other faunal groups. These functions require further investigation through more rigorous controlled experiments, such as removing Tamarix plants or comparing dead nebkhas, and through studies at different scales to examine the processes and mechanisms of biodiversity maintenance by nebkhas.

4.2 The Shelter Effect of Nebkhas Shows Obvious Seasonal Variation

This study reveals significant seasonal variation in both the abundance and species composition of ground beetles. Beetle abundance peaked in June 2005

and July 2006, likely related to interannual climate variation and flooding. Precipitation was relatively low in 2005 but higher in 2006, with correspondingly greater surface runoff. To avoid flood impacts or better utilize soil moisture, beetles may congregate on nebkhas for refuge or maintain relatively high populations post-flood. However, the relationship between flooding and animal populations is complex and requires further research. Wenniger et al. also demonstrated that irrigation effects influence insect diversity more than plant diversity in late summer.

This study demonstrates the beneficial effects of nebkhas on maintaining ground beetle community diversity and species richness in desert areas, and their shelter function for ground beetles. During agricultural reclamation, protection of nebkhas should be prioritized to better maintain insect diversity and the balance of desert ecosystems.

Note: Figure translations are in progress. See original paper for figures.